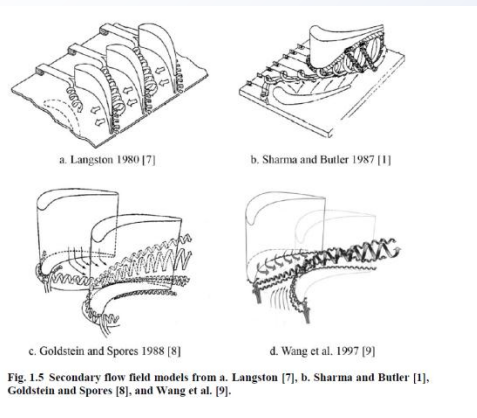


Holistic Aeropropulsion Concepts

NASA Aeronautics Research Institute



Principal Investigator: Vikram Shyam – GRC/RTT

Ali Ameri – RTT/OSU

Phillip Poinsette – GRC/RTT

Douglas Thurman – RTT/ARMY

Dennis Culley – GRC/RHC

Peter Eichele – GRC/FTC

Sameer Kulkarni – GRC/RTT

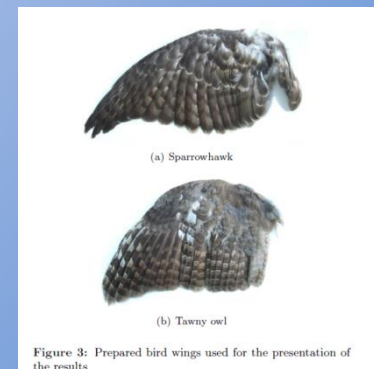
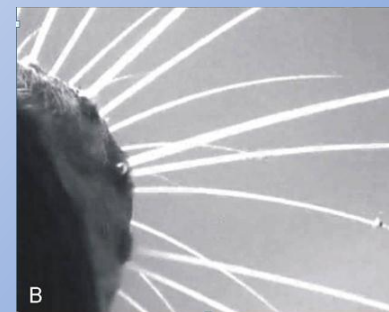
Herb Schilling – GRC/VEO

Christopher Snyder – GRC/RTM

Surya Raghu – Advanced Fluidics LLC

Mike Zelek – GRC/FTC

Adam Wroblewski – GRC/RHI



NASA Aeronautics Research Mission Directorate (ARMD)

2014 Seedling Technical Seminar

February 19–27, 2014



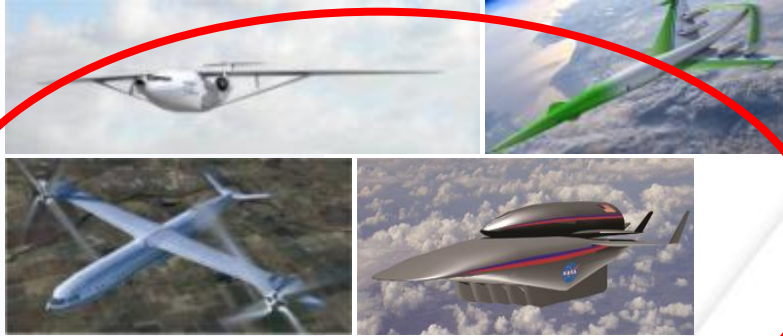
Outline

NASA Aeronautics Research Institute

- **Motivation**
- Background
- Objectives
- Approach
 - Biomimicry
 - Autonomous Closed-Loop Flow Control (ACFC)
- Results
- Conclusions



NASA Aeronautics Programs



Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.



Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.



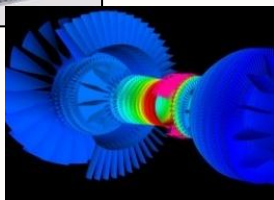
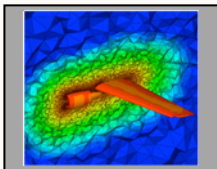


FA Program Organization Structure

NASA Aeronautics Research Institute

Fundamental Aeronautics Program Office

Aeronautical Sciences Project



Aeronautical Sciences (AS)

Enable fast, efficient design & analysis of advanced aviation systems from first principles through physics-based tools, methods, & cross-cutting technologies.

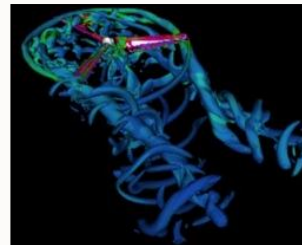
Fixed Wing Project



Fixed Wing (FW)

Explore & develop technologies and concepts for improved energy efficiency & environmental compatibility of fixed wing, subsonic transports

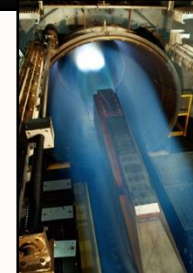
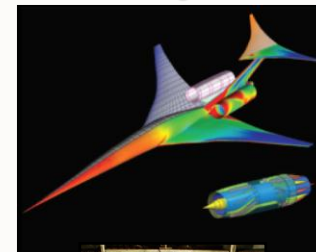
Rotary Wing Project



Rotary Wing (RW)

Enable enable radical changes in the transportation system through advanced rotary wing vehicles concepts & capabilities.

High Speed Project



High Speed (HS)

Enable tools & technologies and validation capabilities necessary to overcome environmental & performance barriers to practical civil supersonic airliners.



NASA Subsonic Transport System Level Metrics

.... technology for dramatically improving noise, emissions, & performance

NASA Aeronautics Research Institute

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption [‡] (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO₂ emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used



Outline

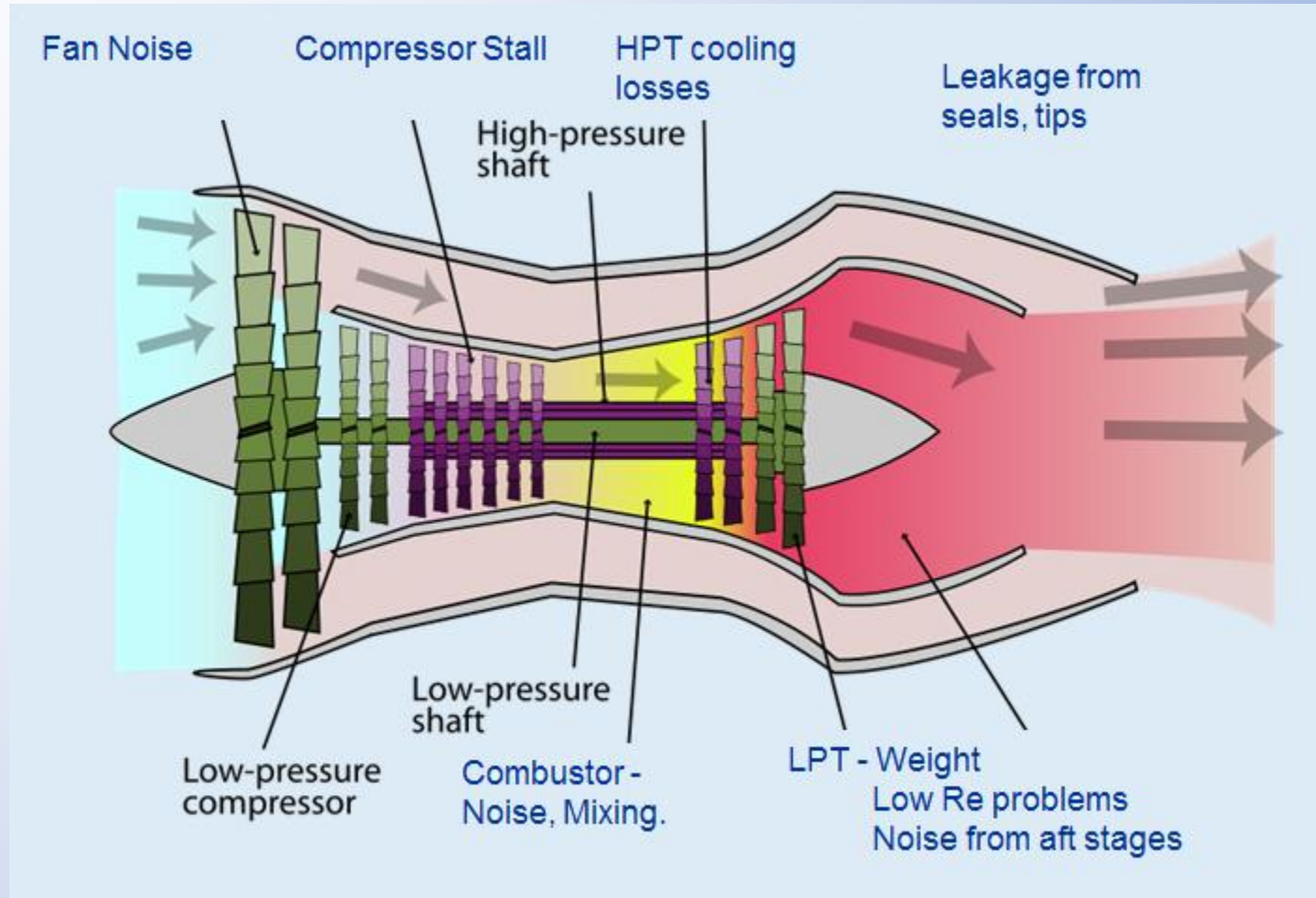
NASA Aeronautics Research Institute

- Motivation
- **Background**
- Objectives
- Approach
 - Biomimicry
 - Autonomous Closed-Loop Flow Control (ACFC)
- Results
- Conclusions



Sources of Performance Hits

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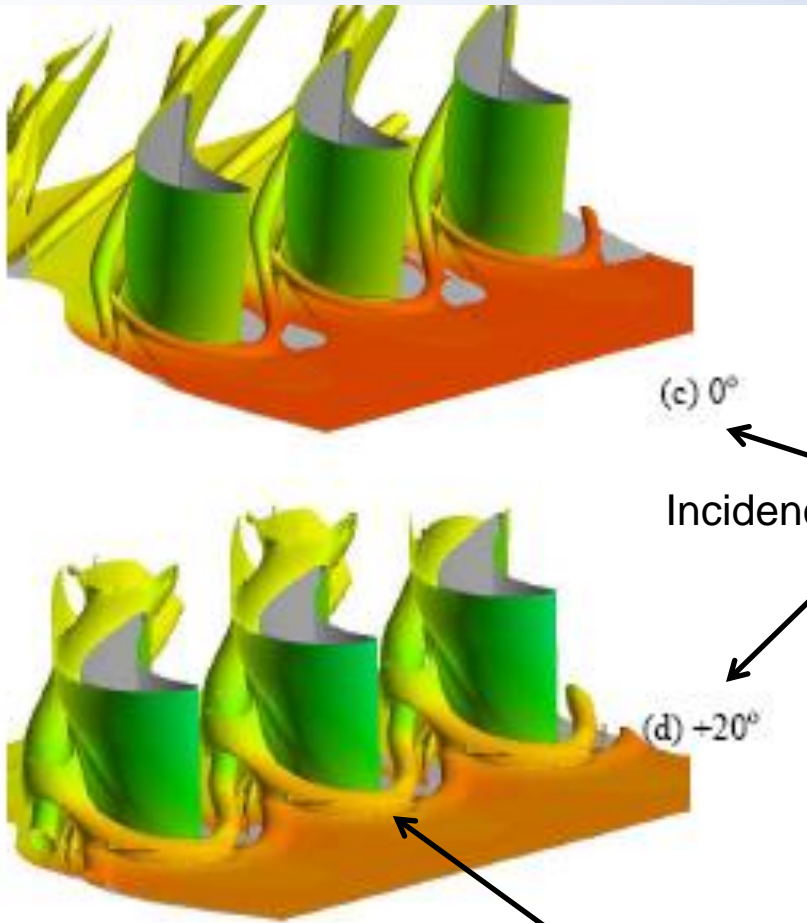


http://en.wikipedia.org/wiki/File:Turbofan_operation_lbp.svg

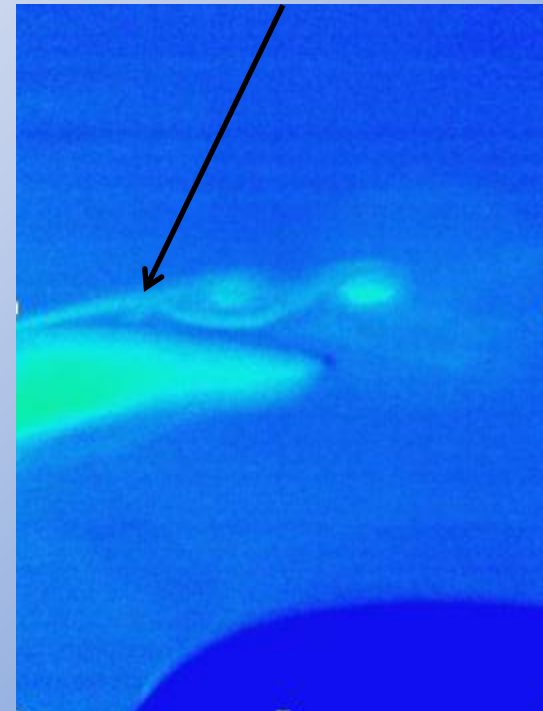


Incidence, Low Re Problems

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Separation due to
adverse pressure





Flow Control

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- Flow control attempted
 - Requires power
 - Local effects that could be detrimental elsewhere
 - Cannot adjust to changing environment
 - VGJs extensively researched
 - Blowing into BL is common
- Design compromise by averaging over mission
- Noise reduction by blowing into wake costs 5% compressor bleed – unacceptable
- Sensing of flowfield and thermal field requires sensors/power
 - trades performance for weight and cost



Biomimicry

NASA Aeronautics Research Institute

- Imitating Life
- Using natural multi-parameter multi-objective optimization to solve aeropropulsion challenges
 - Get something for almost nothing
- Challenges
 - Geometric/ fluid dynamic scaling
 - Identifying relevant physics to incorporate

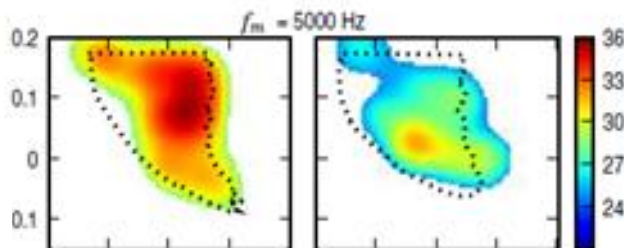


Known Bio-inspired Solutions

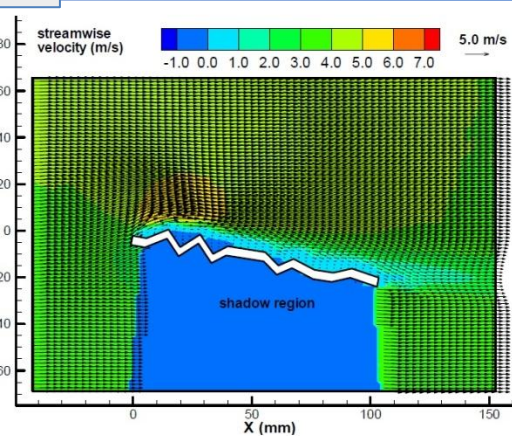
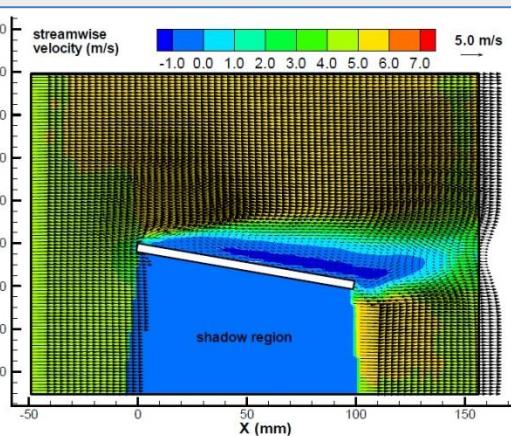
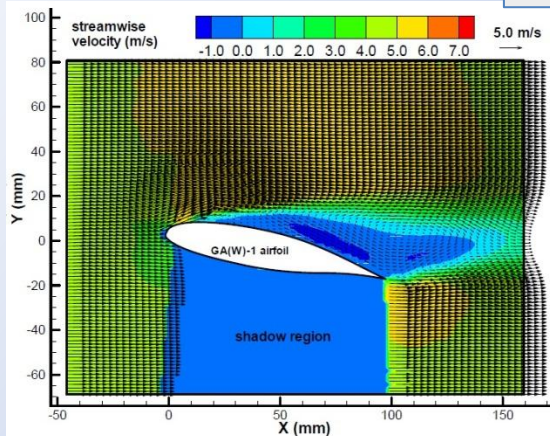
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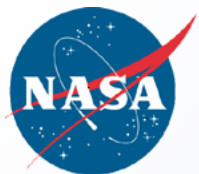
Fish et al., "The Tubercles on Humpback Whales' Flippers: Application of Bio-Inspired Technology" .



Geyer et al., "Silent Owl Flight, Experiments in the Aeroacoustic Wind Tunnel"

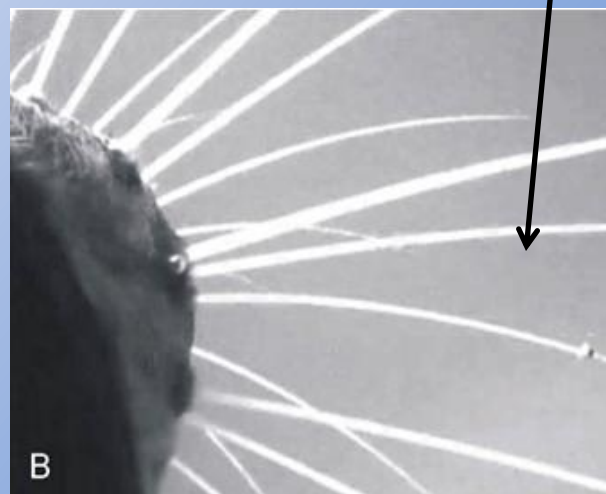
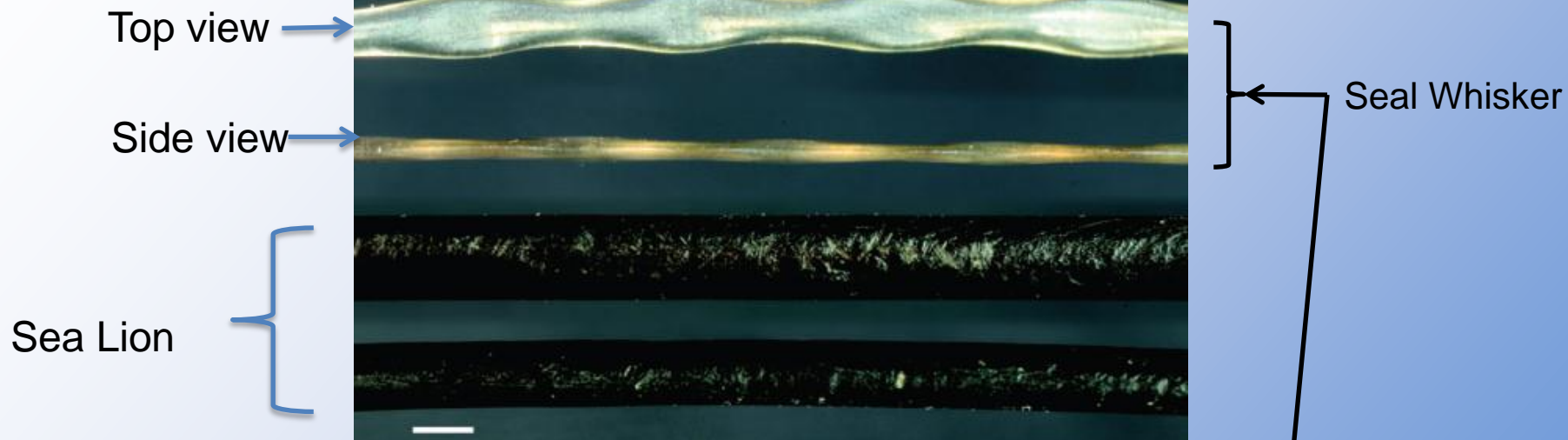


Tamai et al., "Aerodynamic Performance of a Corrugated Dragonfly Airfoil Compared with Smooth Airfoils at Low Reynolds Numbers"



Harbor Seal

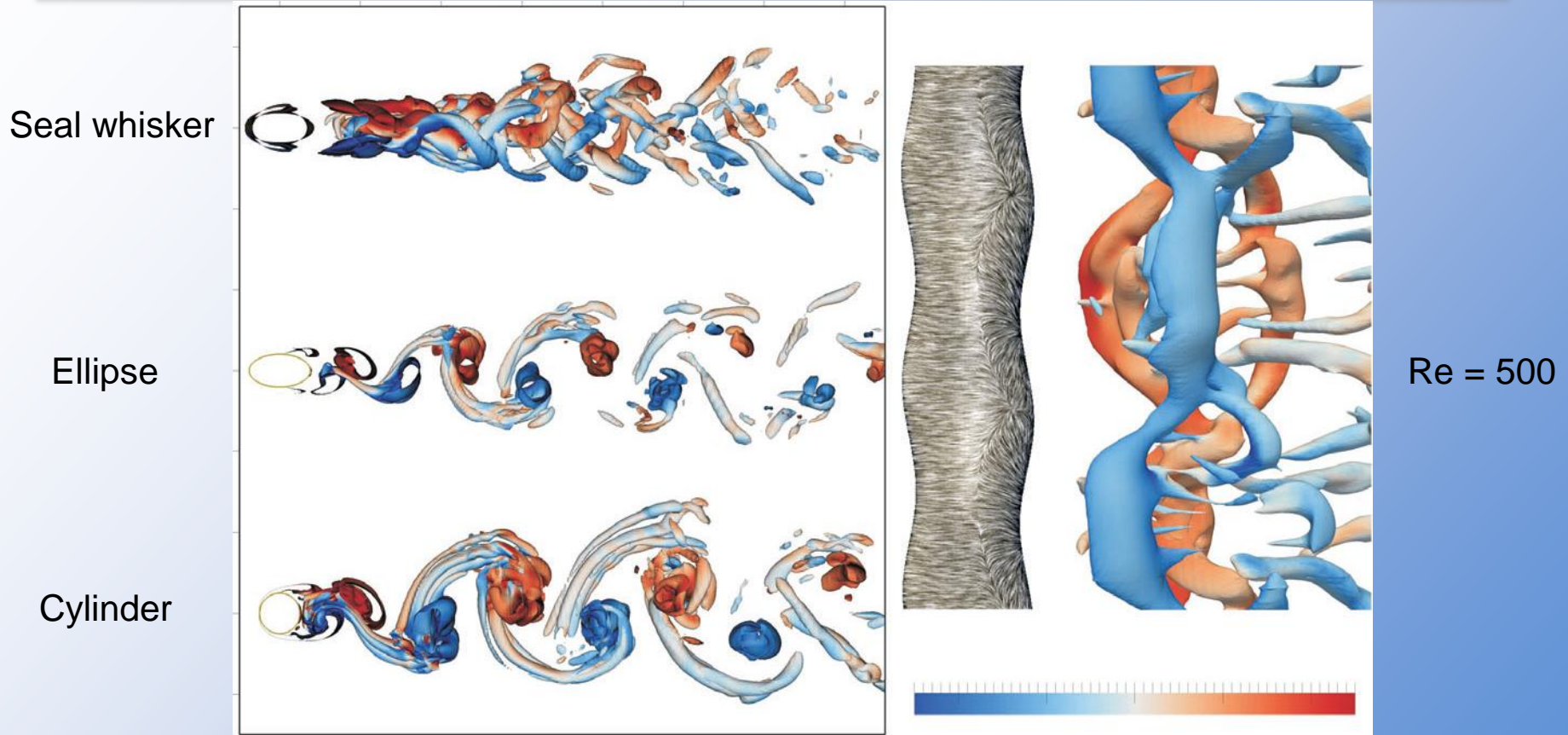
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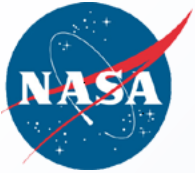
Harbor Seal

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PIV on vibrissae at U of Rostock. Witte et al. 2012. Figure shows Q-criterion

- 40% mean drag coefficient reduction over cylinder
- 90% reduction of unsteadiness



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Objectives – Fundamental Aero

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- Use a holistic approach to
 - Achieve a fuel burn reduction of approximately 3%
 - Achieve noise Reduction of at least 2 db

Through

- a. Passive Biomimicry
 - b. Autonomous Closed-Loop Flow Control (ACFC)
- Biomimetics enables more aggressive design that will benefit further from ACFC
 - While many applications have been studied, infinite possibilities remain



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Biomimetic Features

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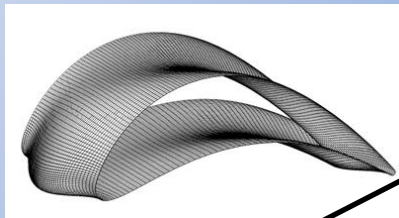
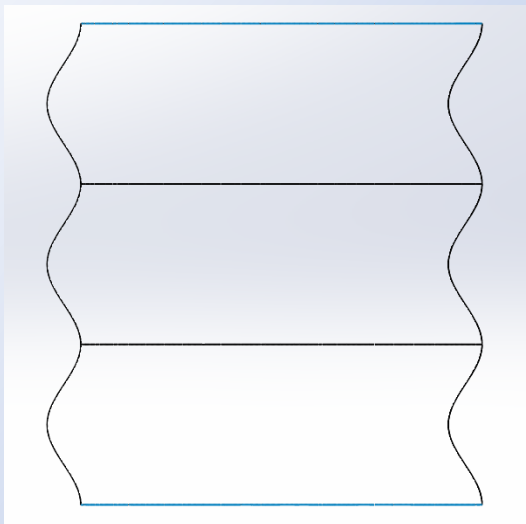
- Achieve delayed separation like seal whisker at High Re
- Achieve distributed wake like seal whisker
- Keep profile drag at or below baseline
- Keep pressure side flow largely unaffected to increase lift/power



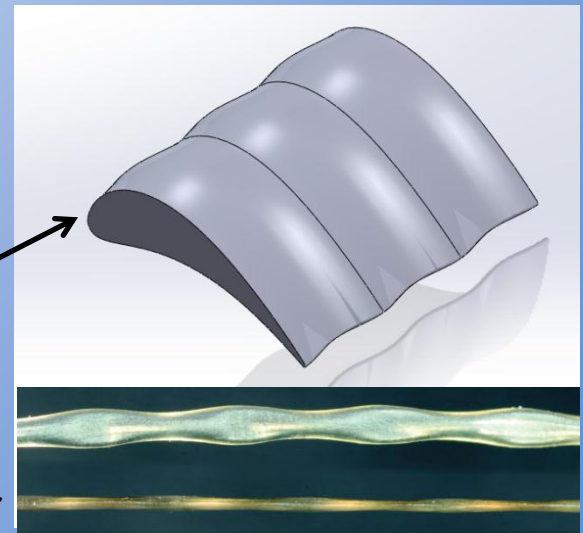
Biomimetic Concept

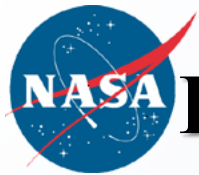
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- Create span-wise pressure gradient on suction side using span-wise undulations
- Push adverse gradient to valleys near trailing edge
- Trailing edge valleys occur at span-wise location of leading edge peaks
- Peaks transition to valleys at crown location



- Amplitude based on LE radius
- Pitch from Seal Whisker





Feasibility Study of Biomimetic Concept

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- Potential flow solutions using MATLAB to understand span-wise pressure gradients
- Unsteady 3D CFD using Glenn-HT
 - Cp distribution at various span-wise locations
 - Average wake pressure-loss coefficient 10% chord downstream of TE
 - Multiple incidence angles
- Wind tunnel testing
 - SW2 cascade facility
 - Total pressure surveys at 10% chord downstream of TE
 - Hotwire surveys at 10% chord downstream of TE
 - Multiple incidence angles



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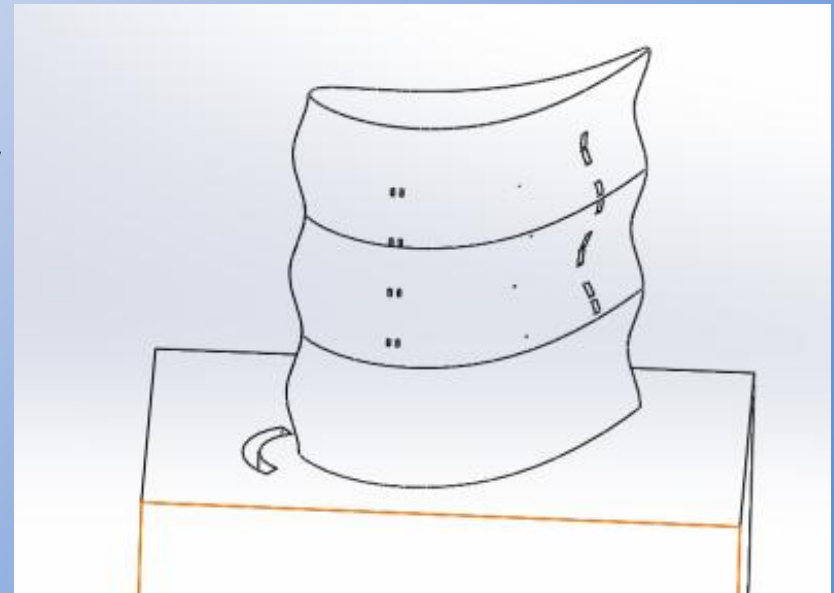
ACFC Concept

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Use suction at the hub to divert BL from horseshoe vortex region and deliver it to regions of separation and TE. This needs to be accomplished without moving parts or external power.

Three Components:

1. Source for flow control
 - Slot upstream of LE on hub
 - Positioned for maximum suction
 - Positioned for maximum secondary flow reduction
2. Performance improvement
 - Pulsed flow at TE and SS
 - Spanwise distributed pulsing slots at TE based on owl feathers.
3. Fluidic control of flow
 - Diverters and pulsing fluidics
 - Manages flow from and to components





Feasibility Study of ACFC

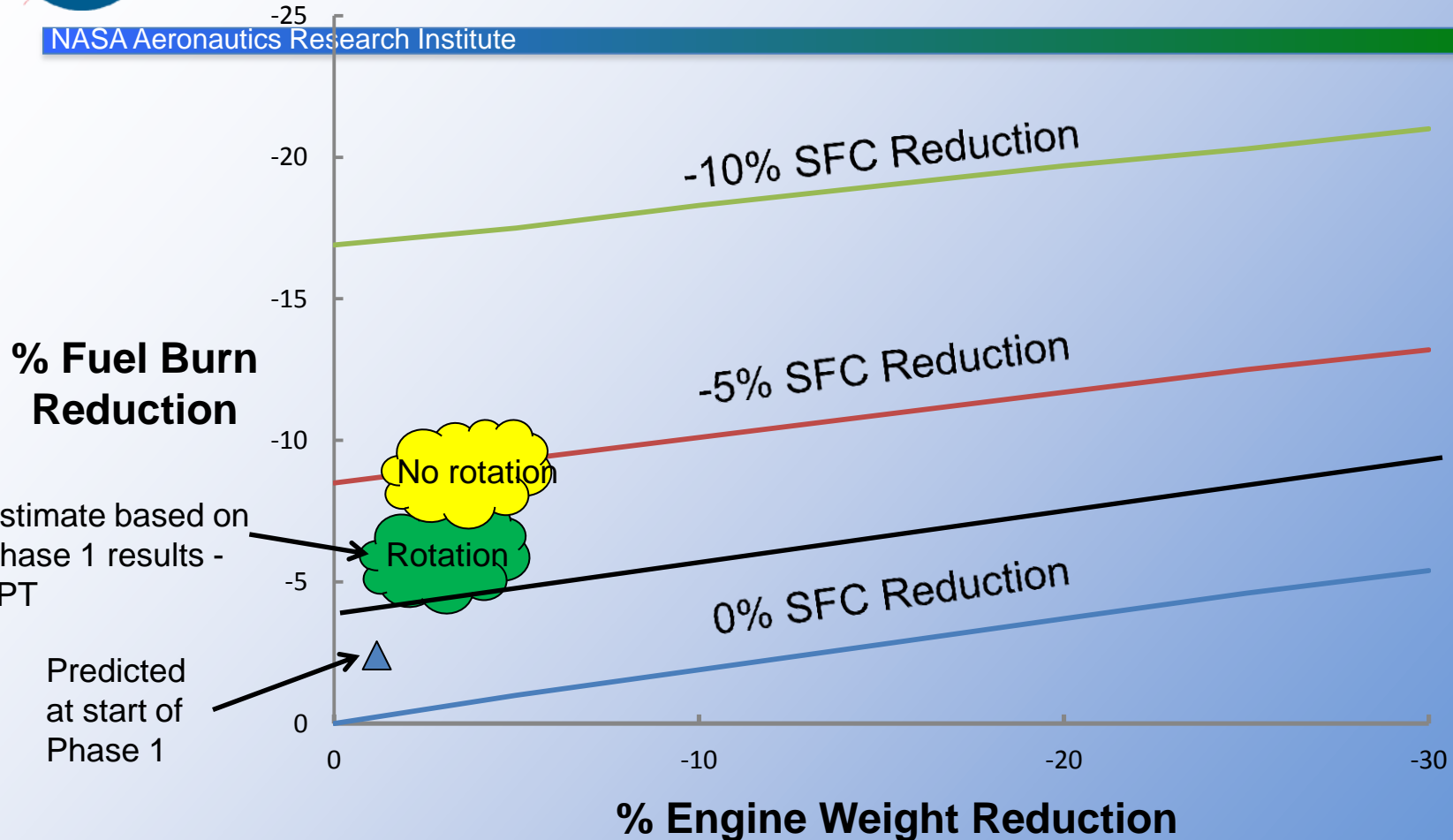
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- 3D unsteady CFD
 - Suction slot upstream of horseshoe vortex saddle point
 - 3D simulation of fluidic actuators
- Wind Tunnel Tests
 - Trailing edge pulsing with hotwire survey
- Fluidic actuator testing using bench-top tests
 - Demonstrate repeatable consistent control
 - Demonstrate versatile control of single fluidic actuator using input signals
- Models created using FORTUS 250mc



Fuel Burn Sensitivities

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- » This was previous work for a 300 PAX aircraft
- » Benefits might be slightly lower for N2A (767 class) aircraft



Contents

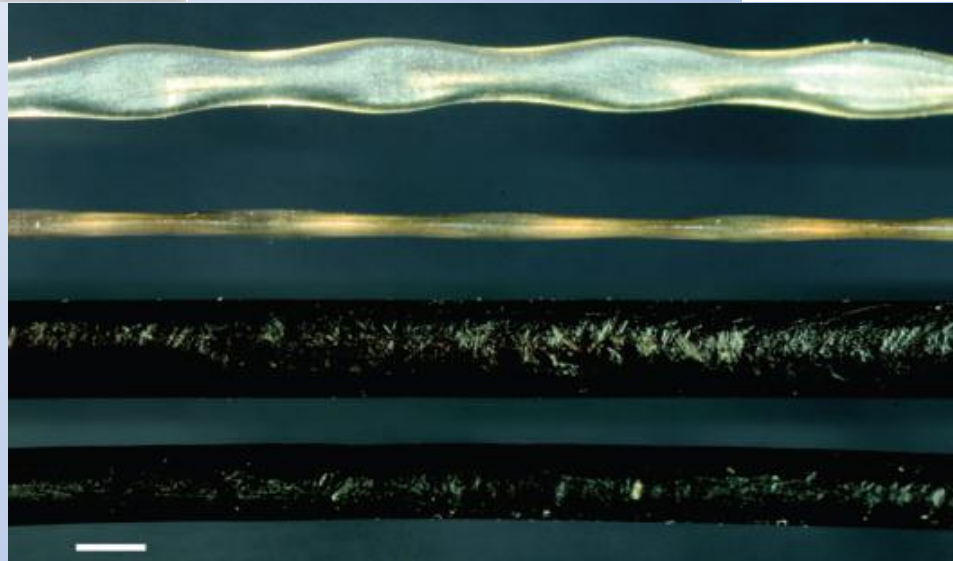
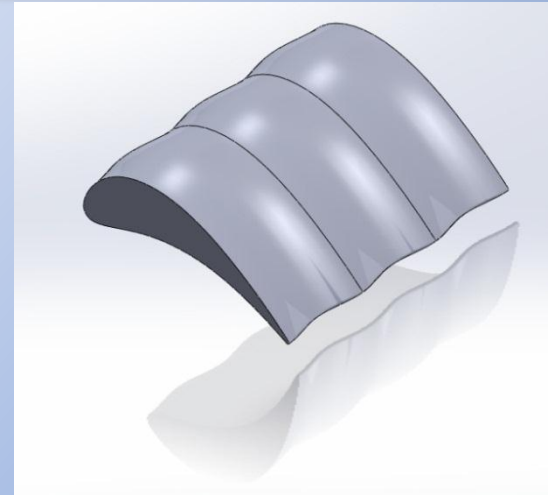
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- Motivation
- Background
- Objectives
- Approach
 - Biomimicry
 - Autonomous Closed-Loop Flow Control (ACFC)
- **Results**
- Conclusions



Biomimicry

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Hanke et al., "Harbor seal vibrissa morphology suppresses vortex-induced vibrations", The Journal of Experimental Biology 213, 2665-2672 © 2010

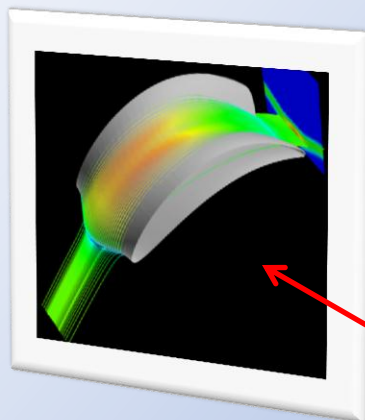
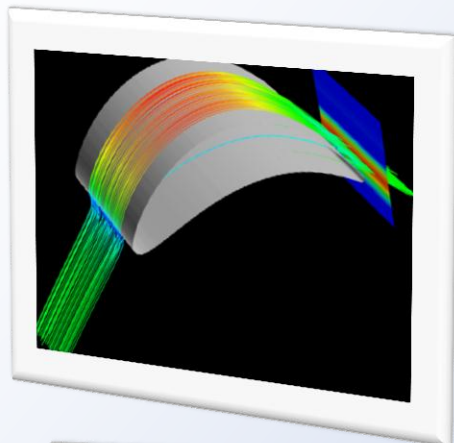


Biomimicry – Seal Blade

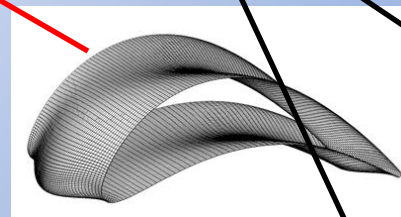
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Rolls Royce VSPT

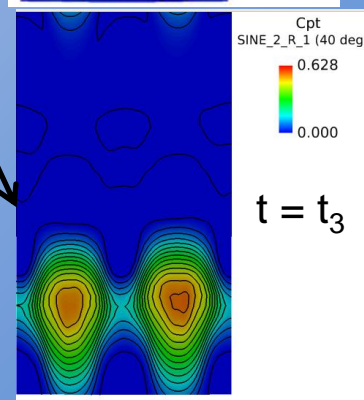
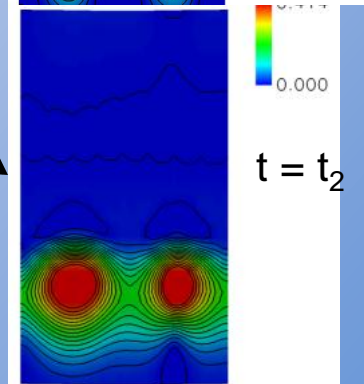
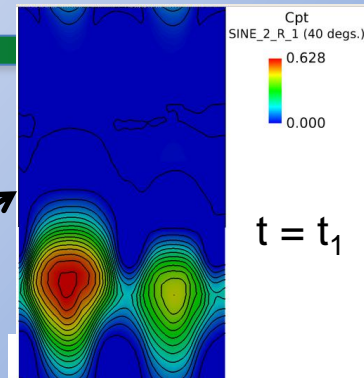
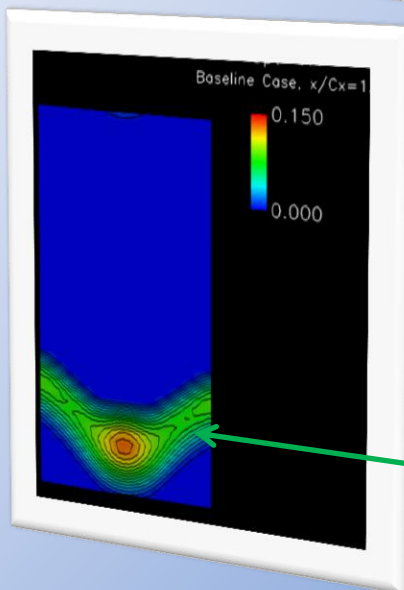
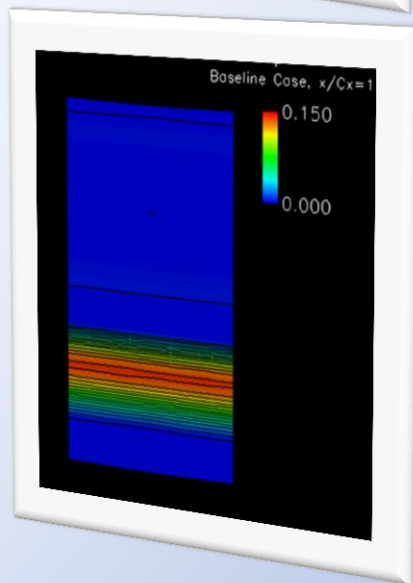
Seal Blade



Noise reduction through wake control



Fuel burn reduction due to elimination of separation



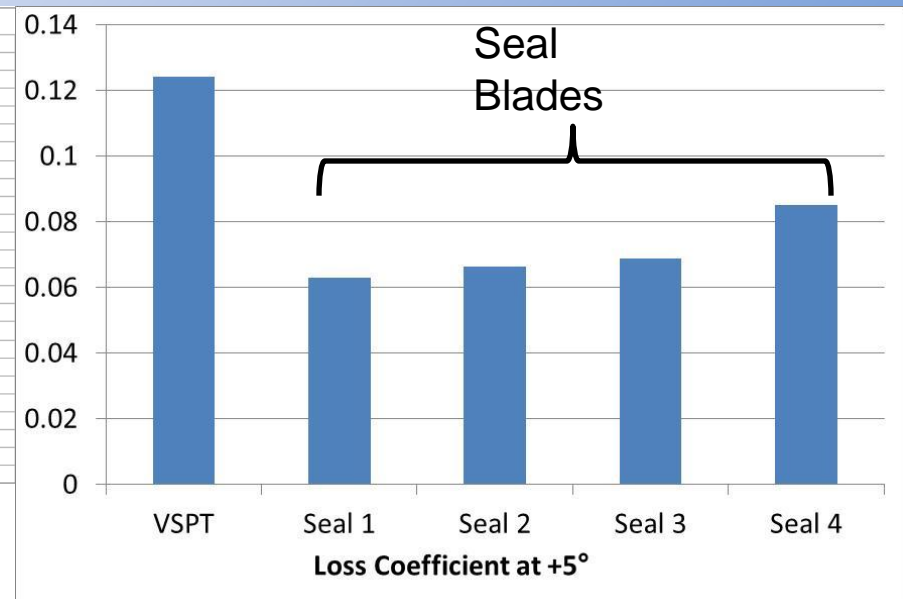
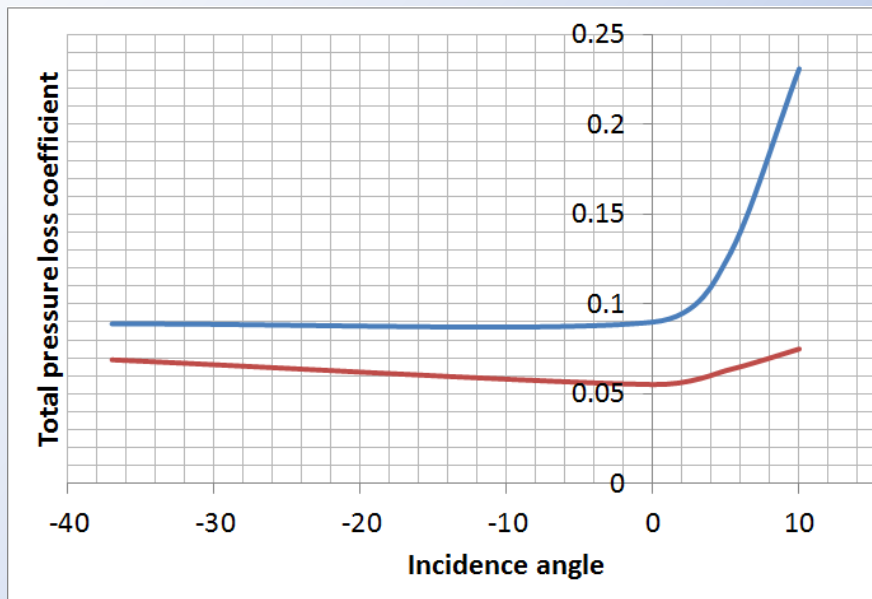


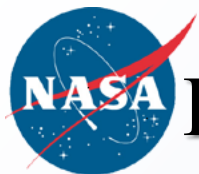
Biomimicry – Performance Improvements

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Incidence tolerance over wide range leads to fuel burn reduction

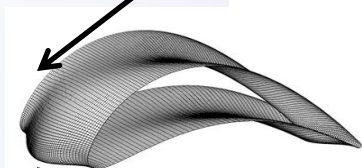
50% improvement in pressure recovery leads to fuel burn reduction





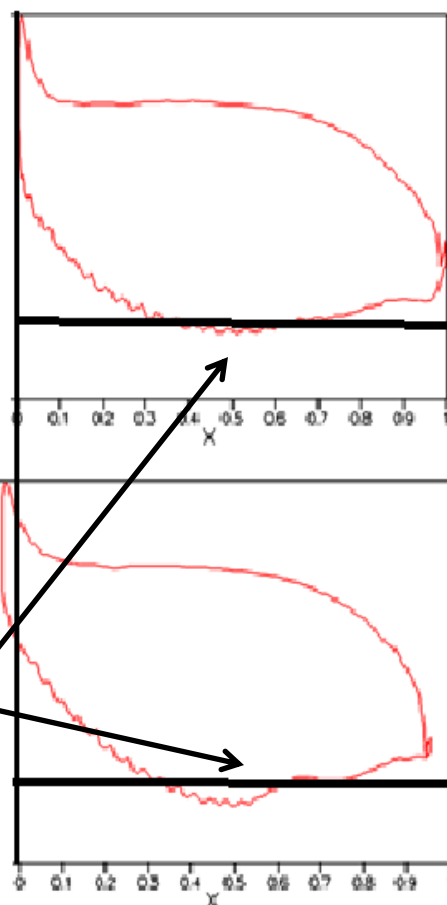
Biomimicry – Seal Blade at 0° Incidence

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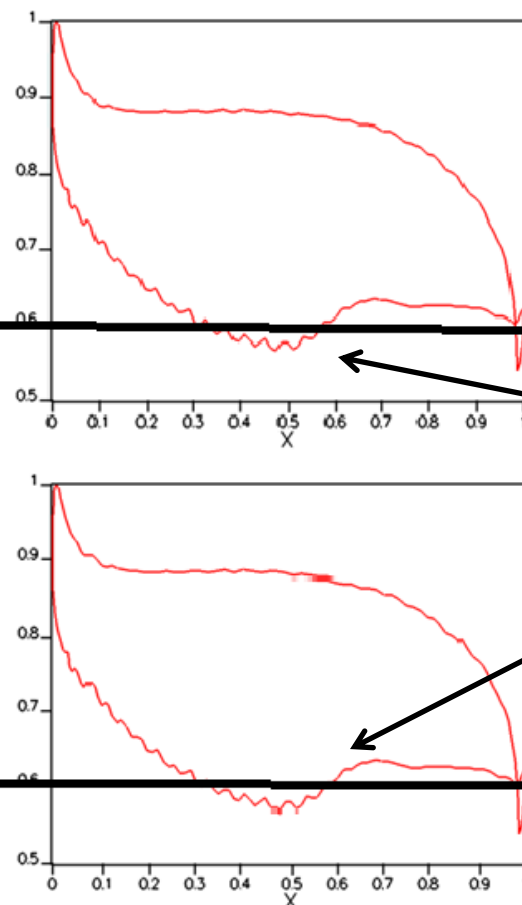


Valley

Peak



Seal Blade



VSPT Blade - no modifications

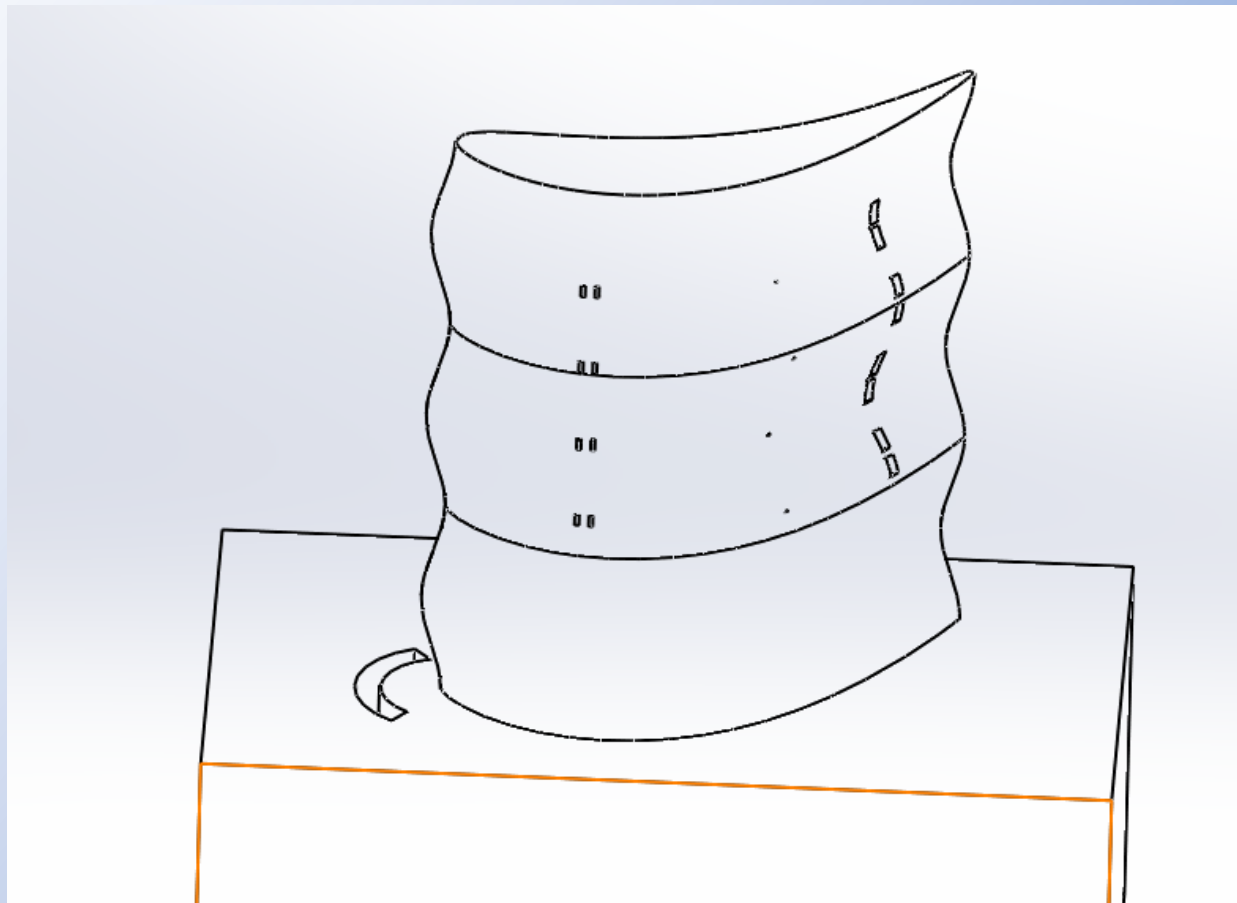
Separation

- Shifts loading in span-wise direction to prevent separation.



Autonomous Closed-Loop Flow Control - ACFC

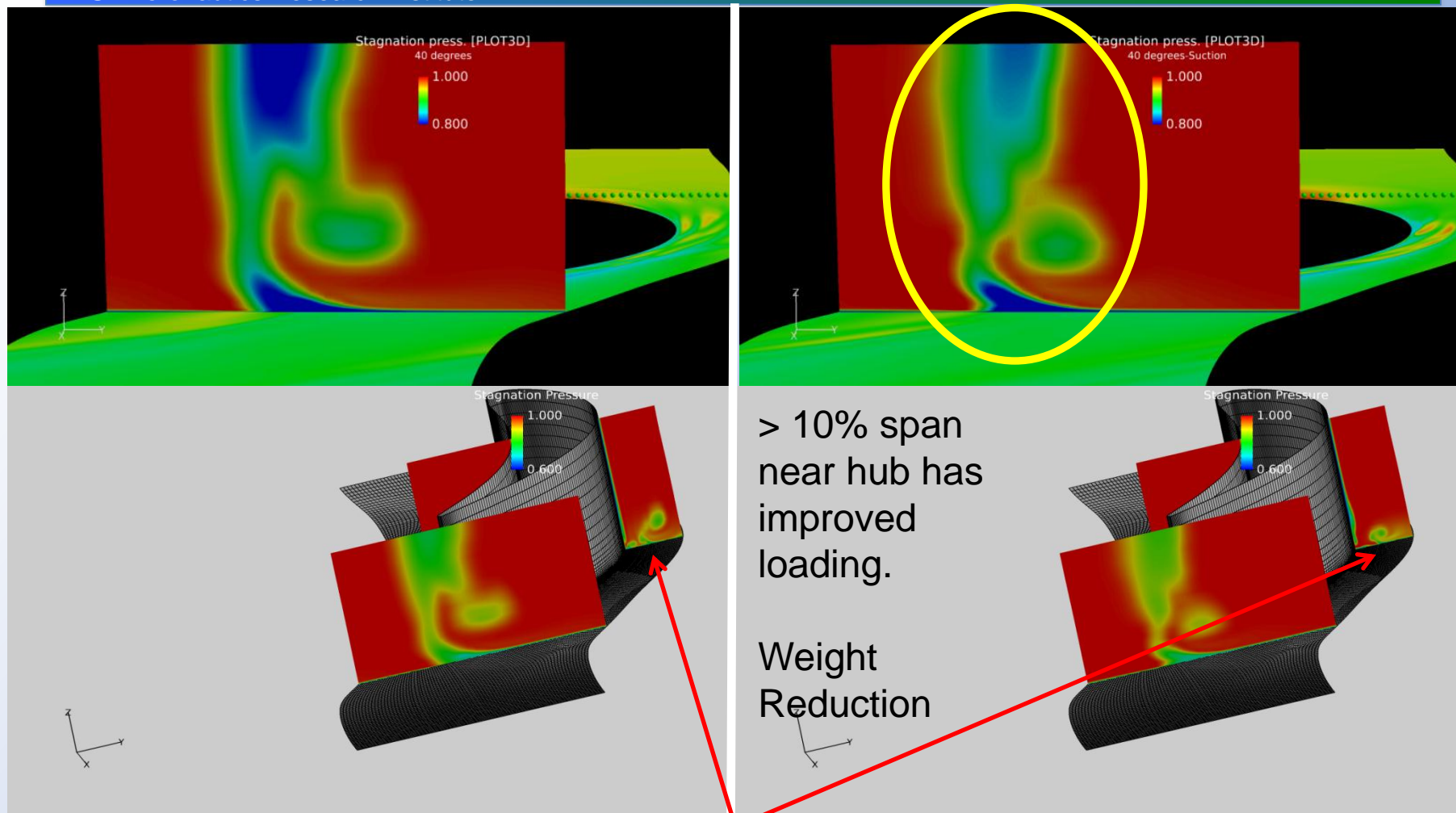
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ACFC – BL Suction

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No suction

horseshoe

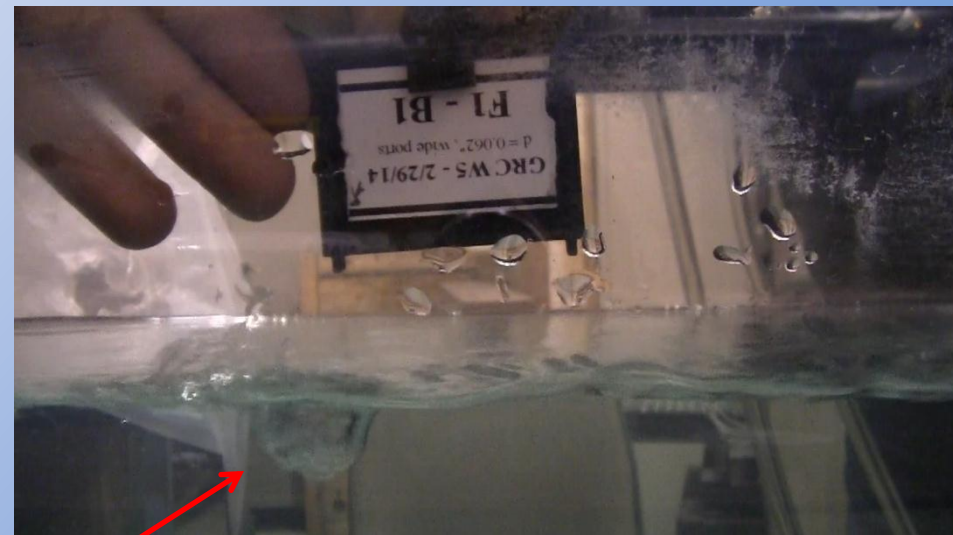
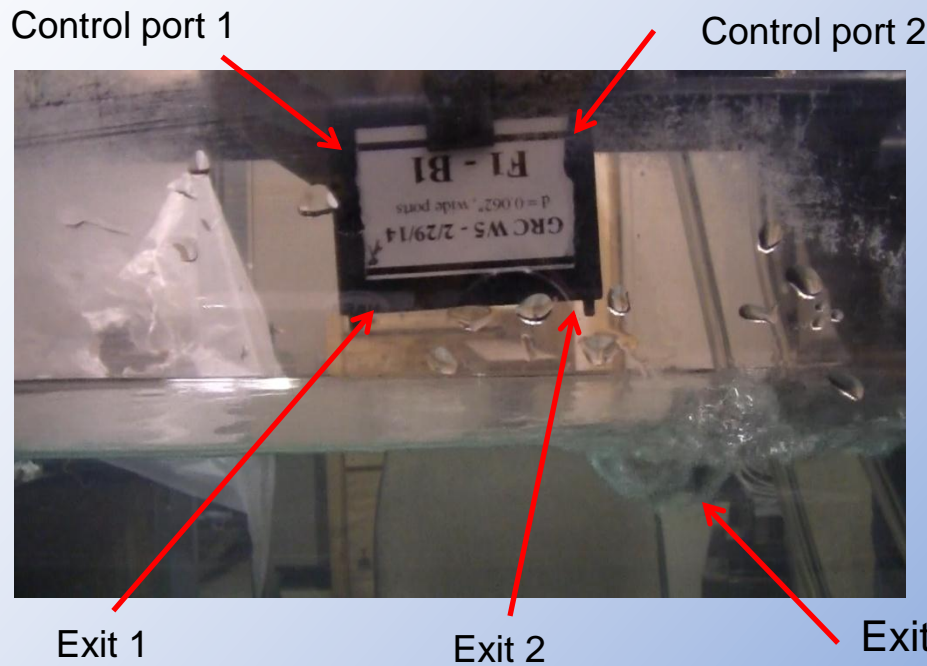
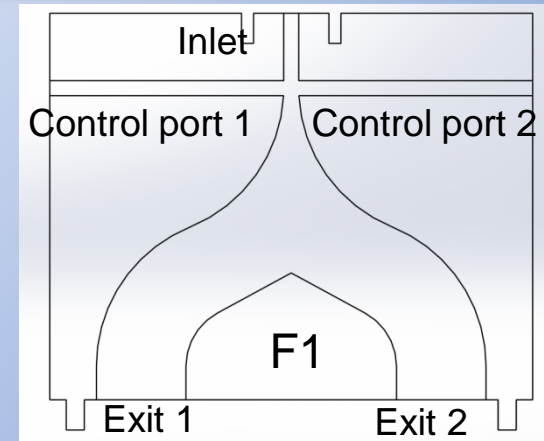
With suction

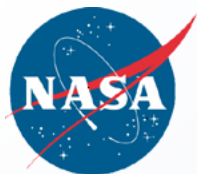


ACFC - Fluidic Devices

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- Showed that for F1, repeatable consistent control is possible
- If port 2 is closed, port 1 controls jet exit such that flow always exits at 2 unless port 1 is closed
- If ports are both open, both control ports can be used to switch flow





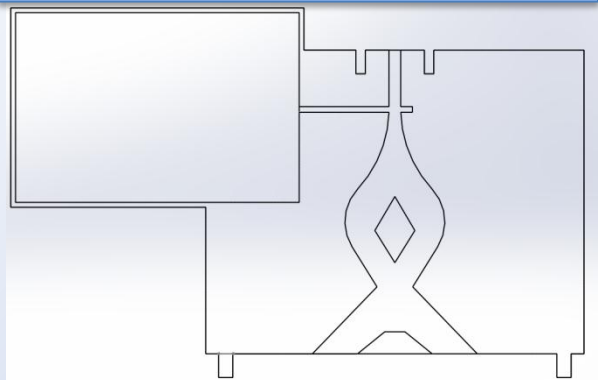
ACFC – Trailing Edge Pulsing

NASA Aeronautics Research Institute

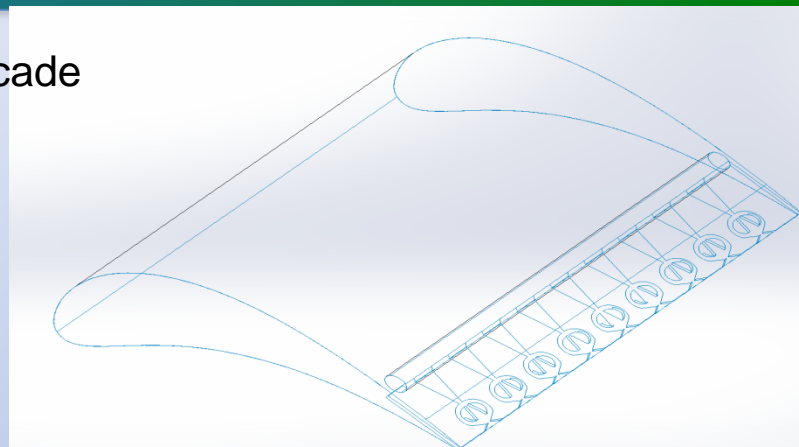


SW-2 cascade
facility

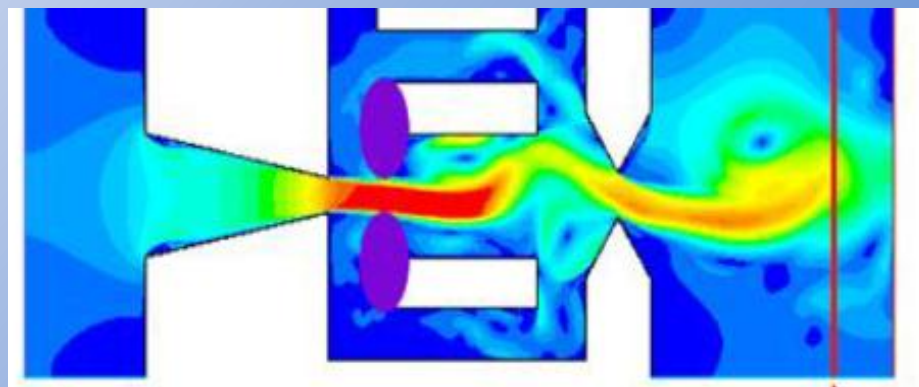
Testing in progress



Helmholtz sweeping fluidic device
New idea – testing in progress
Frequency independent of pressure ratio across device



Numerical Studies of an Array of Fluidic Diverter Actuators for Flow Control. Gokoglu, Suleyman ; Kuczmarski, Maria ; Culley, Dennis ; Raghu, Surya, 2011



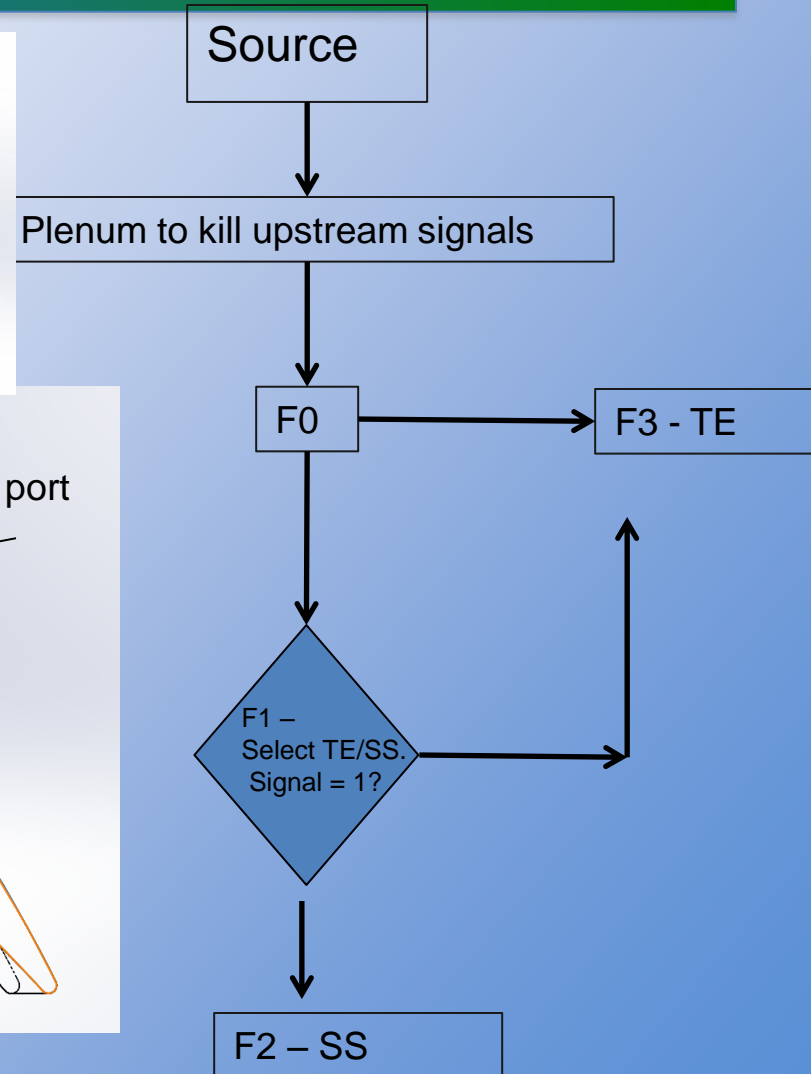
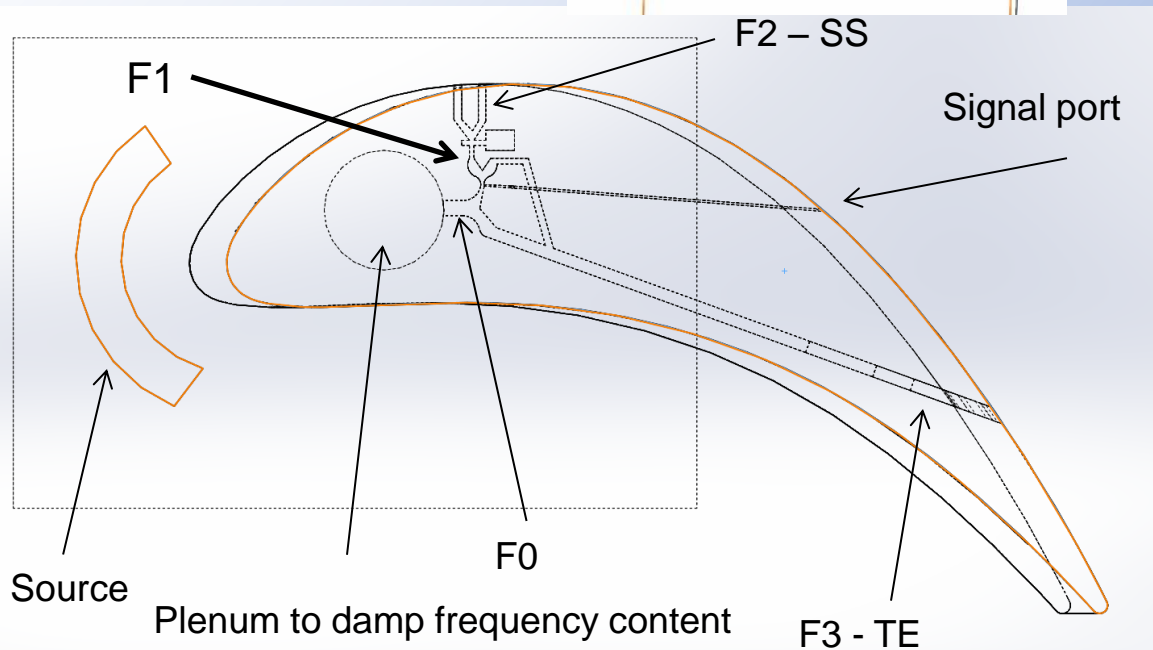
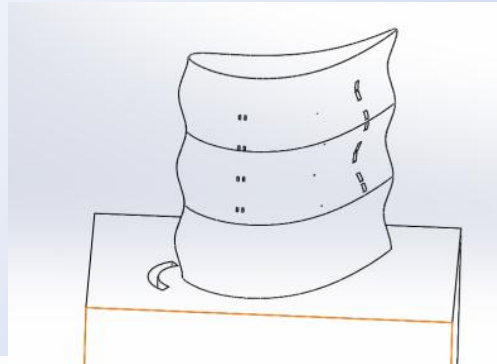
Advanced Fluidics Inc. device with rapid switching. Inventor – Surya Raghu.
Frequency varies with pressure ratio and geometry



ACFC – Concept Diagram

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- F0 – Brancher
- F1 – Diverter
- F2 – Pulser Helmholtz
- F3 – Pulser Fluidic

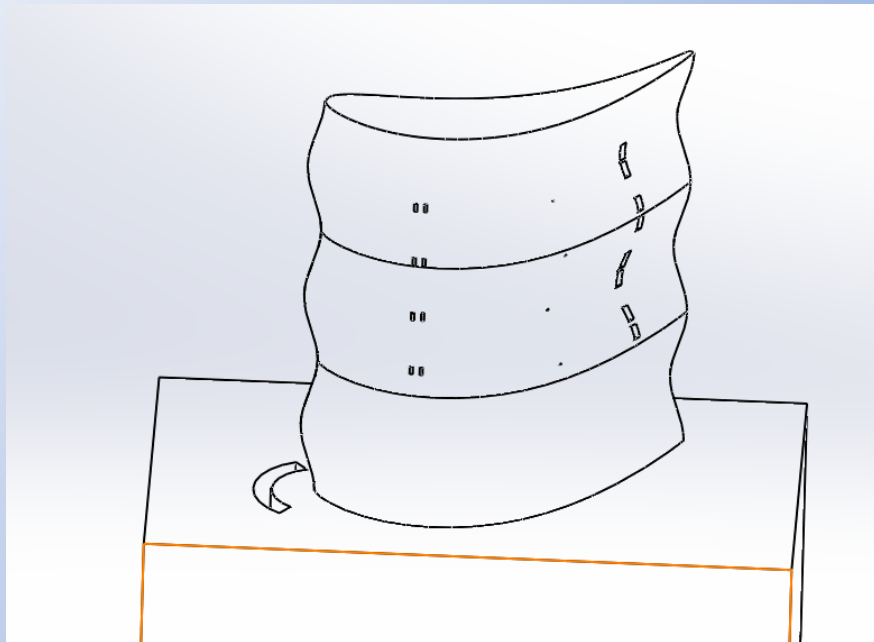




Combination of Biofoils and ACFC for Higher Loading

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- A slot upstream of the Leading edge at the hub for suction
- Plenum to remove incoming signals
- Fluidic network to direct traffic and manage frequency content
- Biofoils to manage separation and incidence tolerance as well as regulate passage vortex and reduce noise
- Trailing edge slots with spanwise pulsing (adjacent slots pulse out of phase)





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NASA Aeronautics Research Institute

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Conclusions

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- Feasibility of Biomimetic geometry shown for Fuel burn reduction
- Feasibility of Autonomous Closed-Loop Flow Control concept shown (waiting on TE pulsing results)
- Major benefit of this system is that no external power or electronics is required
- The system self-adjusts to changing flow conditions.
- At least 3% Fuel burn reduction and 2db noise reduction are possible
- More can be achieved by applying to fan, compressor, airframe



Patents Pending

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- Holistic system concept
 - Endwall flow control
 - Wake noise reduction
 - Fluidic network concept
- Seal-type aerodynamic surface design
 - Electric cables, helicopter rotors, tail, turbine engine components
 - Parameters for optimization
- Helmholtz Fluidic switcher
- Porous owl-type aerodynamic surface
 - Mimicking of owl wing using virtual airfoil – LE and porous flow control
 - Low noise fan using synthetic owl feathers
 - Compliant wall for subsonic and supersonic flow control
- Novel flow visualization technique using water



Broader Applications

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- Fan blades – wakes, geometry
 - Owl type blades, porous blades
- Compressors – apply similar strategy for stall control
- Turbines
 - Porous trailing and LE. Possible to make a breathing airfoil to eliminate combustor tone?
- Combustor
 - Use fluidic to eliminate tone at source
- Sensors and probes
- Real-time flow measurement and visualization
- Landing gear, struts
- Electrical cables
- External flow – Landing Gear, Struts, Road Signs



Path to Infusion

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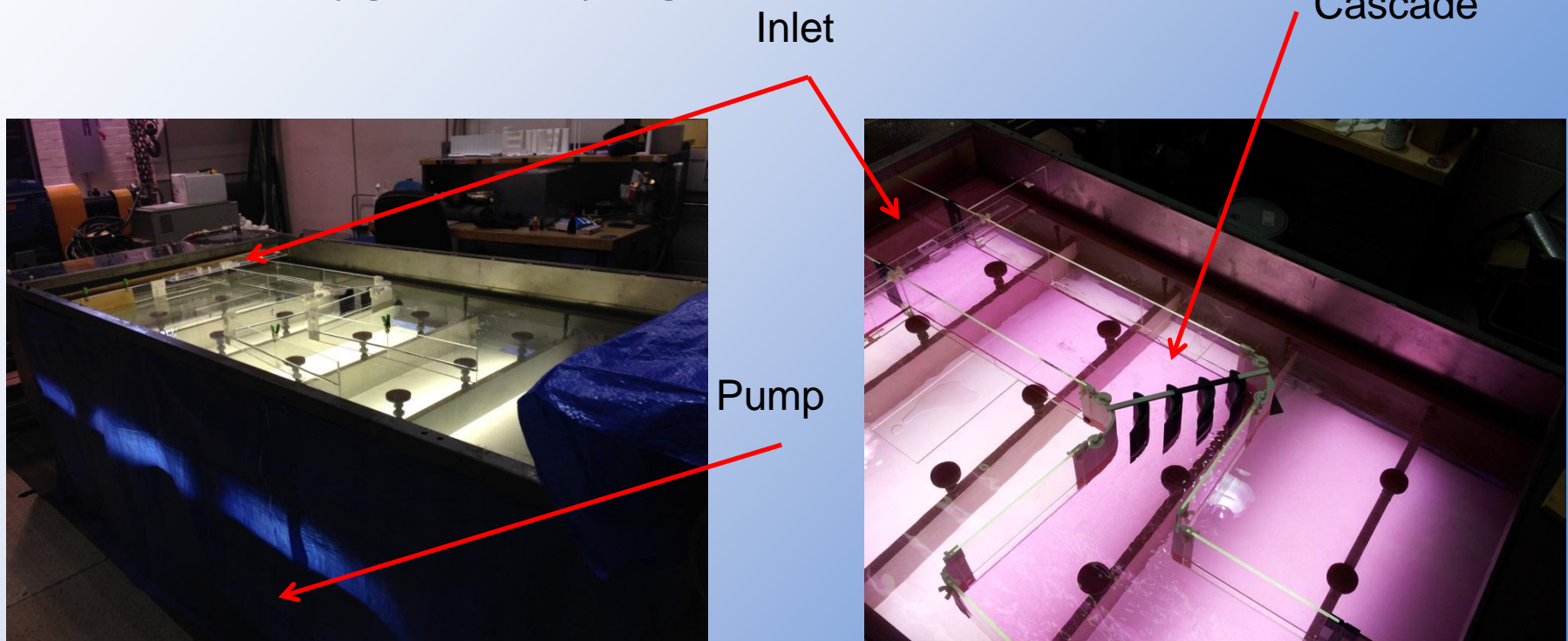
- Raise to TRL 3 in Phase 2
 - Include effect of rotation
 - Apply biomimetics to fan and compressor blades
 - Pulsed blowing for fan noise reduction
 - Fabricate and test complete fluidic network on benchtop
 - Test fluidic network within RR VSPT blade in SW-2
 - CW-22 testing at matched Re and Mach
 - Optimization of geometry using COMSOL/MATLAB/Solidworks
 - Extend Seedless Velocimetry measurement methods
 - Testing of biomaterials in SW-2, water table
- Elements are of interest to
 - Fixed Wing – propulsion efficiency, acoustics
 - Aerosciences – Flow Control, Novel measurement techniques



Flow Visualization for Phase 2

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- Water table set up in SE-1 facility
- Instrumentation installed – XBOX Kinect, IR camera, scales for depth measurement
- Further upgrades in progress



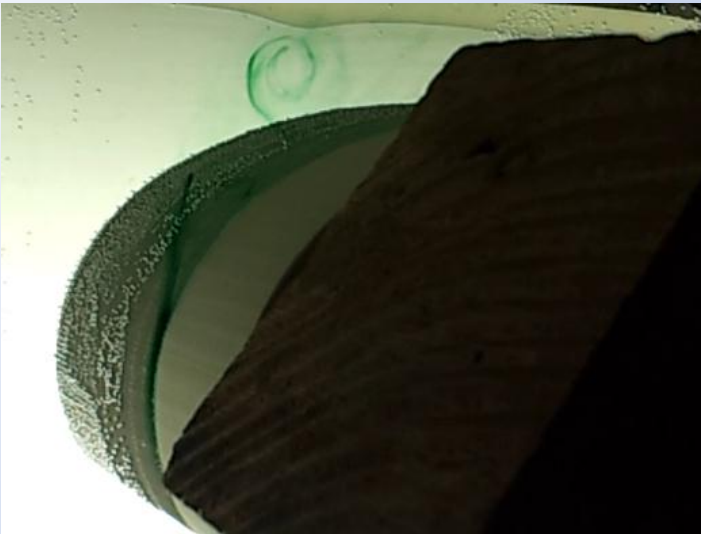


Dye Injection - Visible

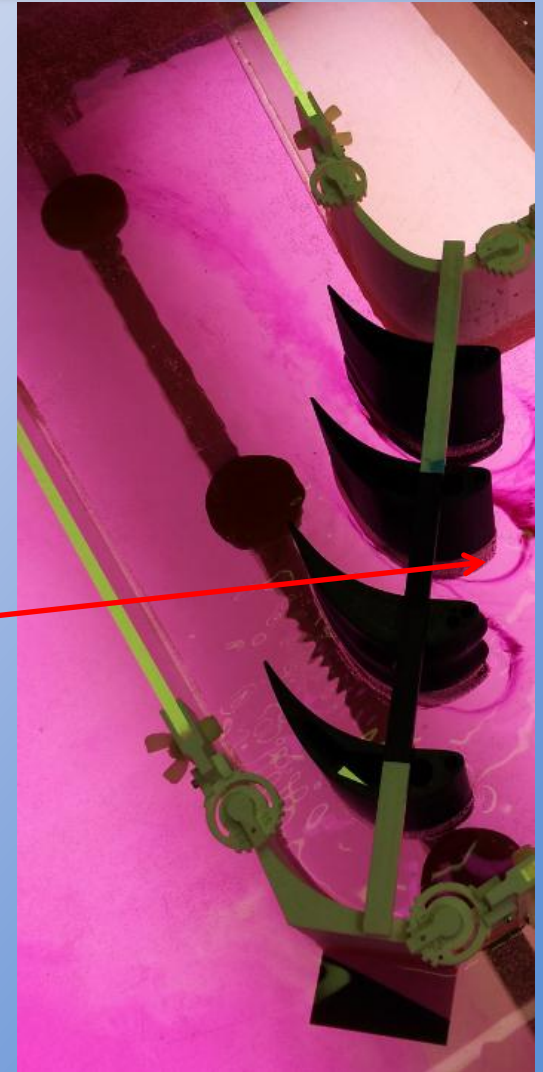
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IR camera view



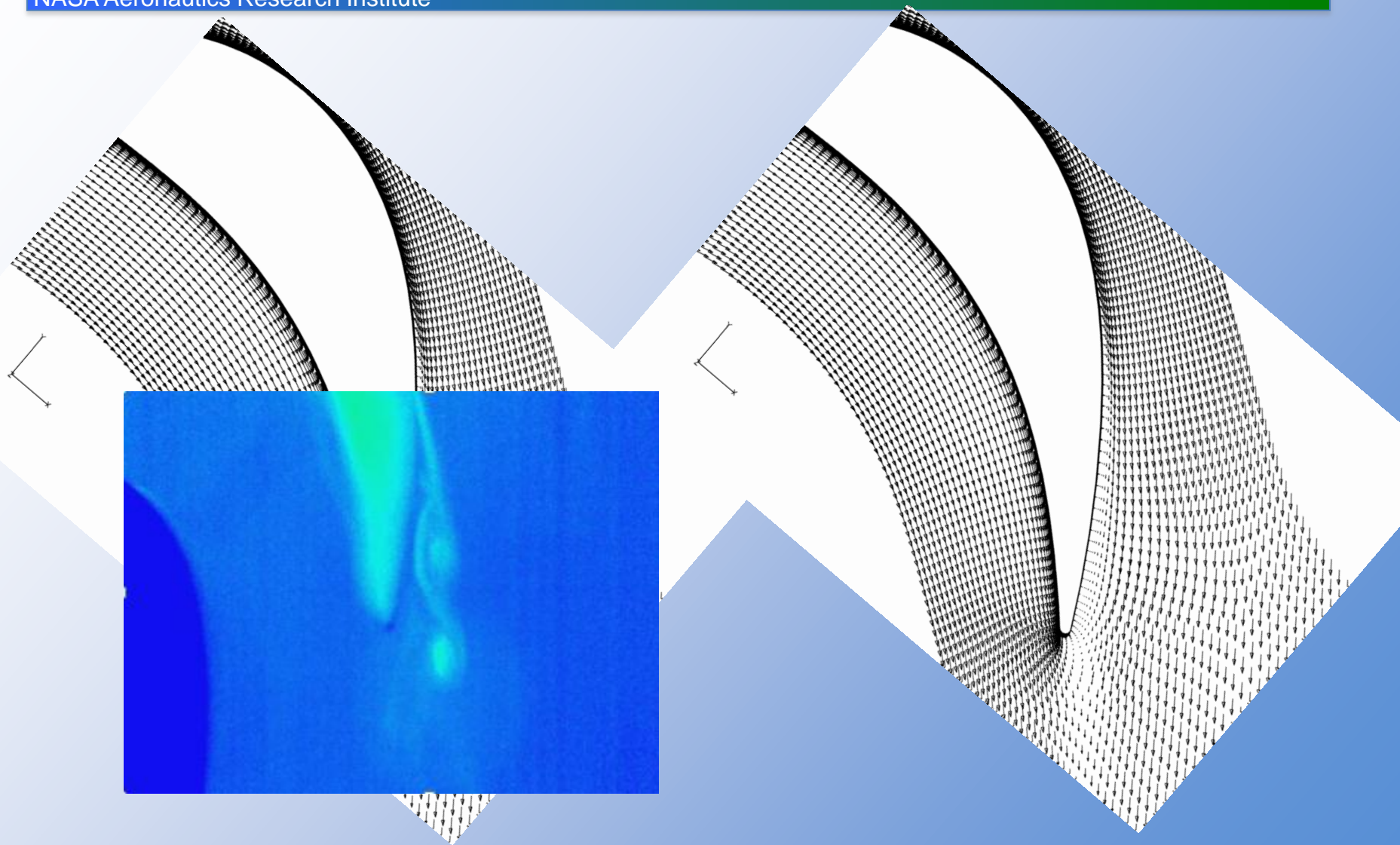
Horseshoe
location





Infrared Flow Vis.

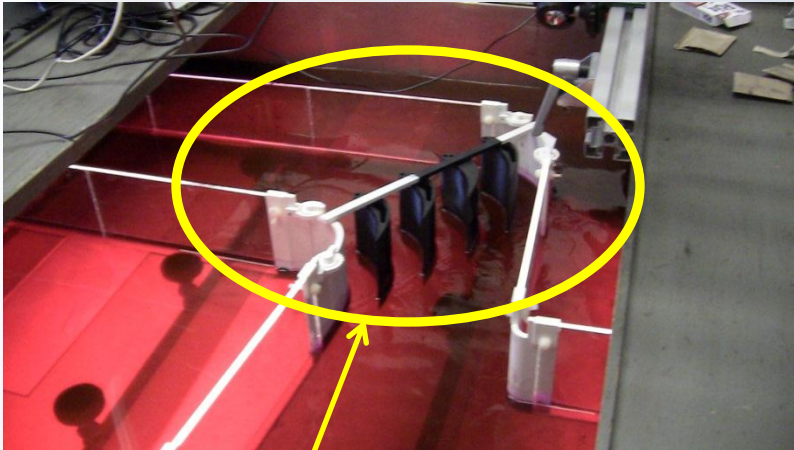
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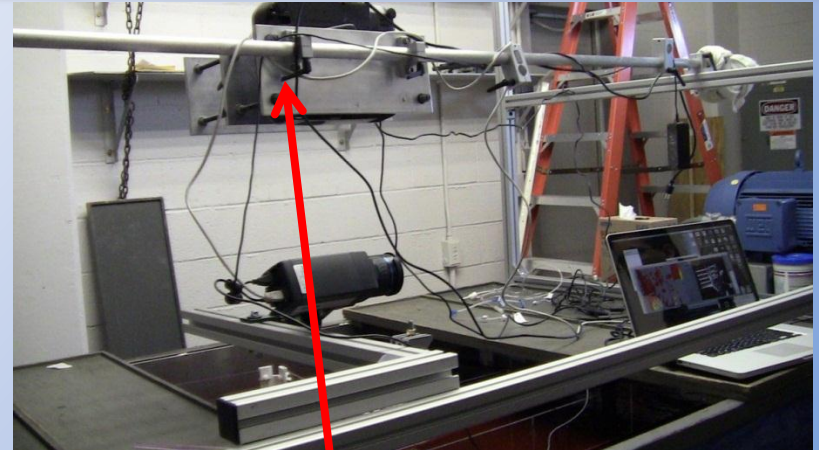


Real-time Quantitative Flow Vis.

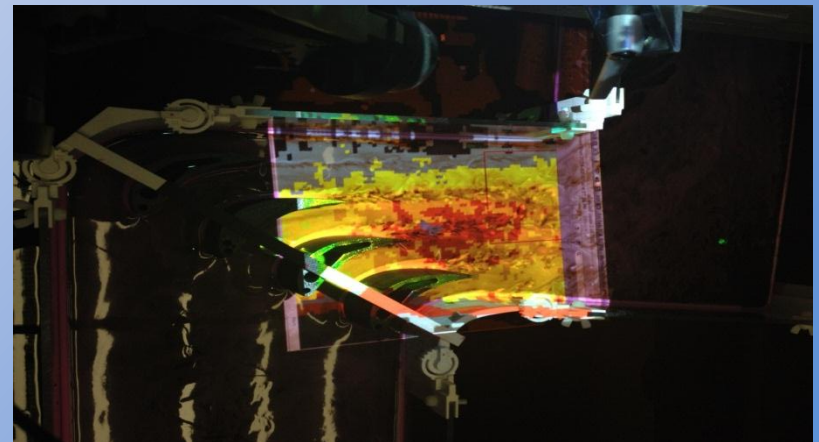
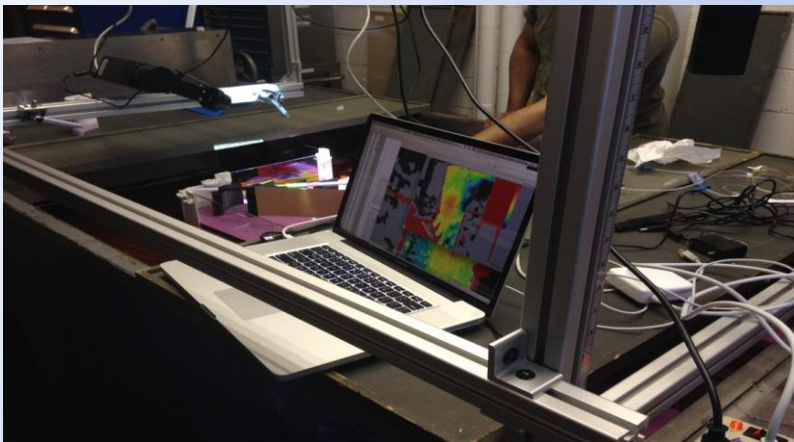
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Cascade



XBOX Kinect and projection system





Phase 2 Collaboration - External

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- Microsoft
- Harp technology
- Advanced Fluidics
- Georgia Tech
- Cleveland State University
- Marine Mammal Center, San Diego
- Cleveland Zoo
- GLBio

U Akron Biomimicry Fellows

Emily (Boston)

Kelly (Hawaii)

Sebastian
(Germany)

Bill (Taiwan)

Daphne (Belgium)

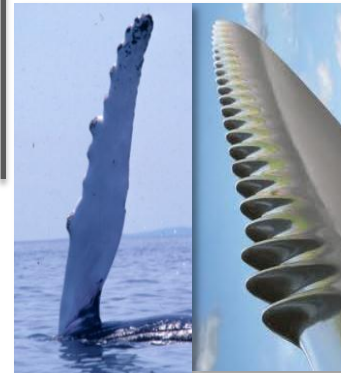
Corporate Biomimicry Sponsors



Building a Biomimicry Discipline



Biomimicry Operationalizes Sustainability





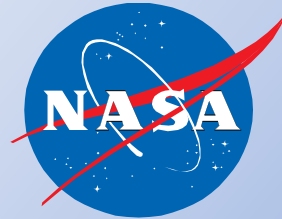
Acknowledgements

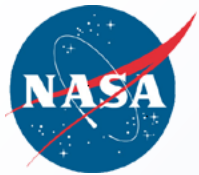
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- Trong Bui, Albion Bowers, Jennifer Cole (NASA DFRC)
- Ali Ahmadi (Cal Poly, Pomona)
- Danielle Koch, Chris Miller, James Heidmann, Gwynn Severt, Jerry Welch, Michael Hathaway, Dennis Huff, D.R. Reddy, Mark Celestina, Milind Bakhle (NASA GRC), GVIZ team
- Krish Ahuja (Georgia Tech)



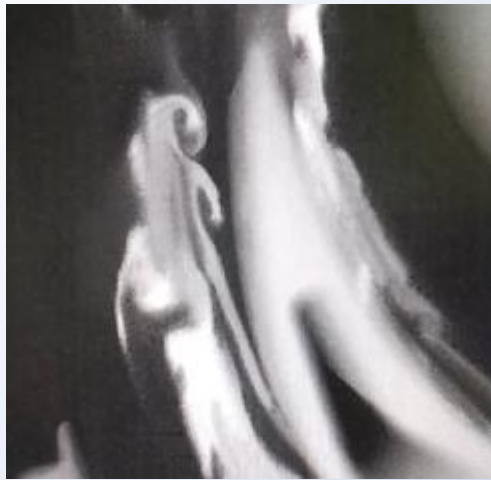
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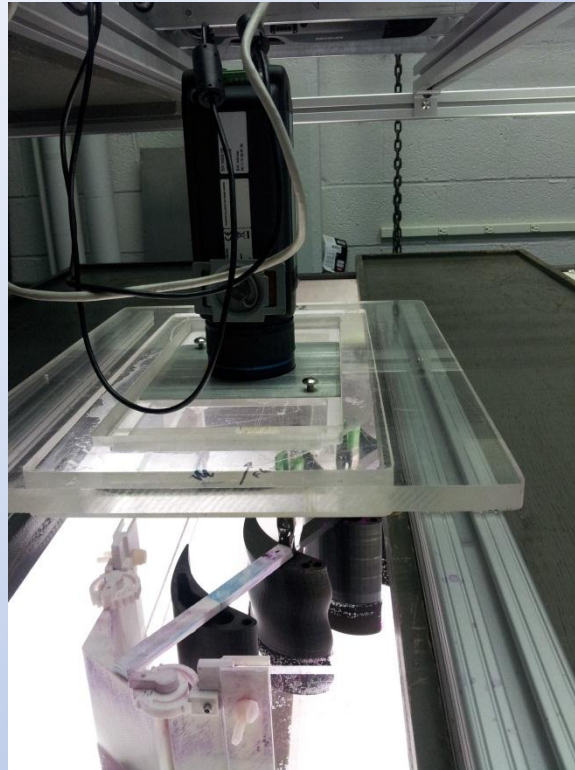


Seal Blade Flow Visualization

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VSPT – 0 incidence



IR Setup

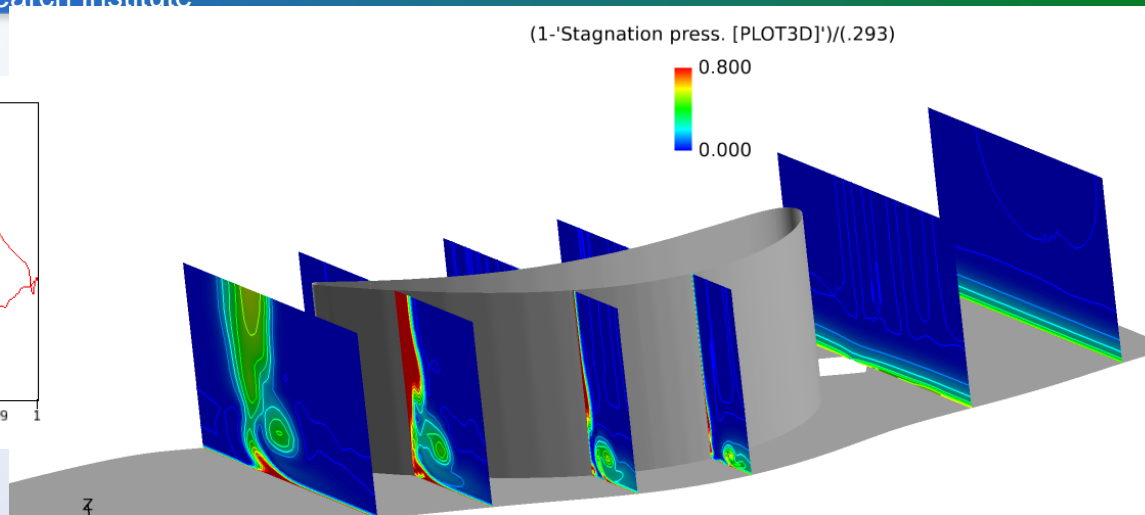
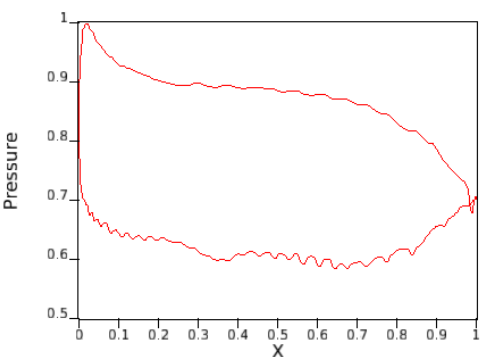


Seal Blade – 0 incidence

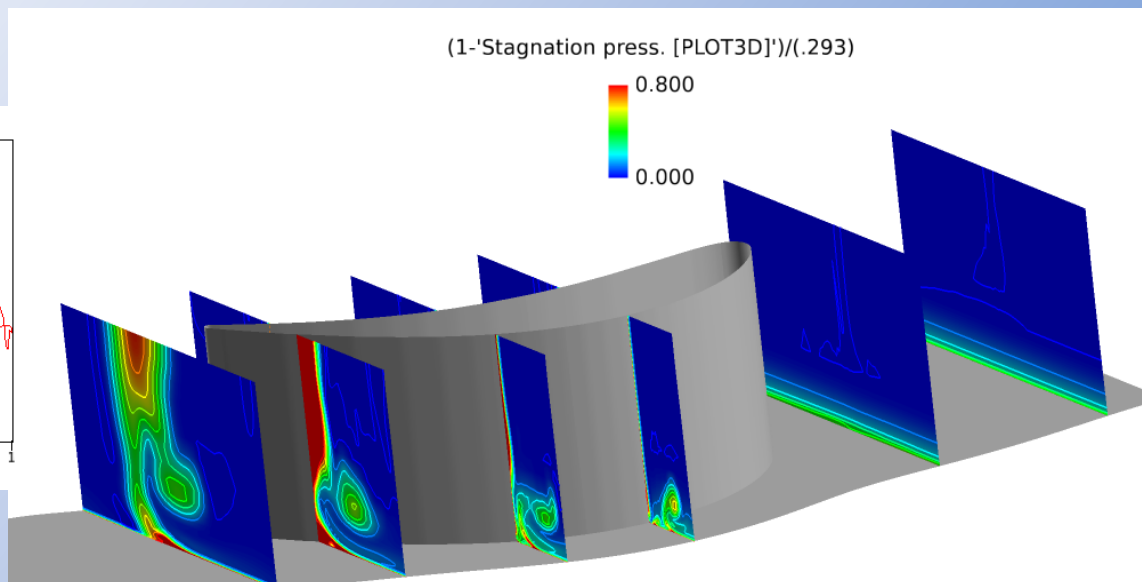
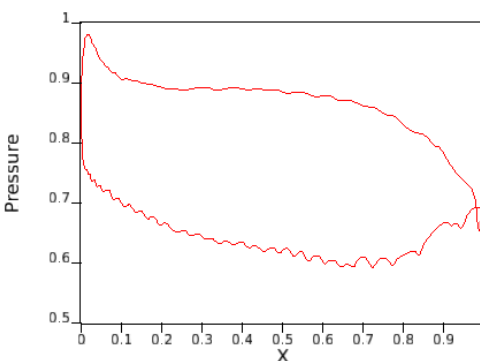


ACFC Suction Results

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With
Suction

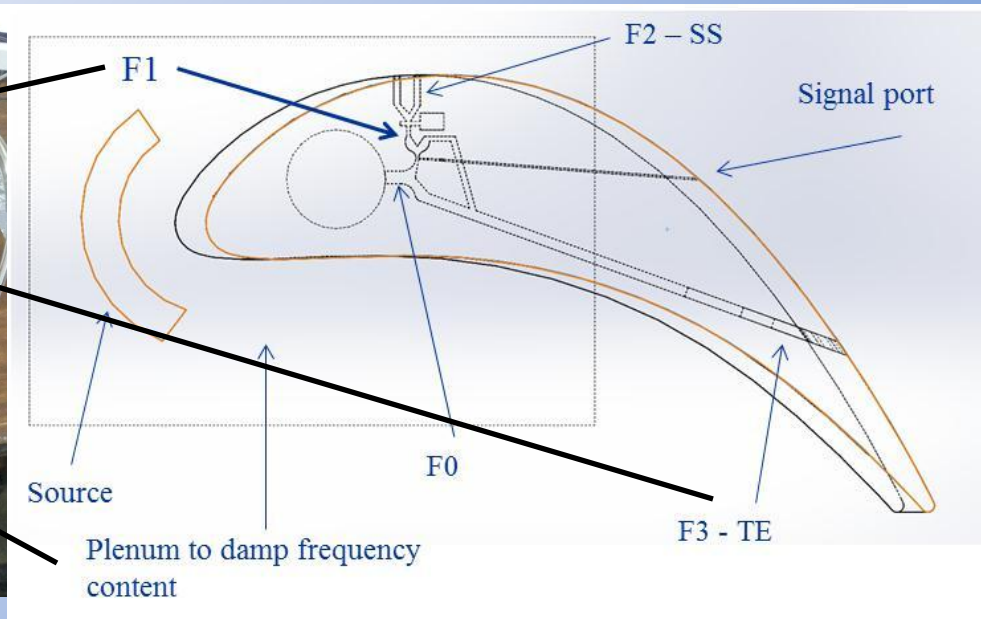
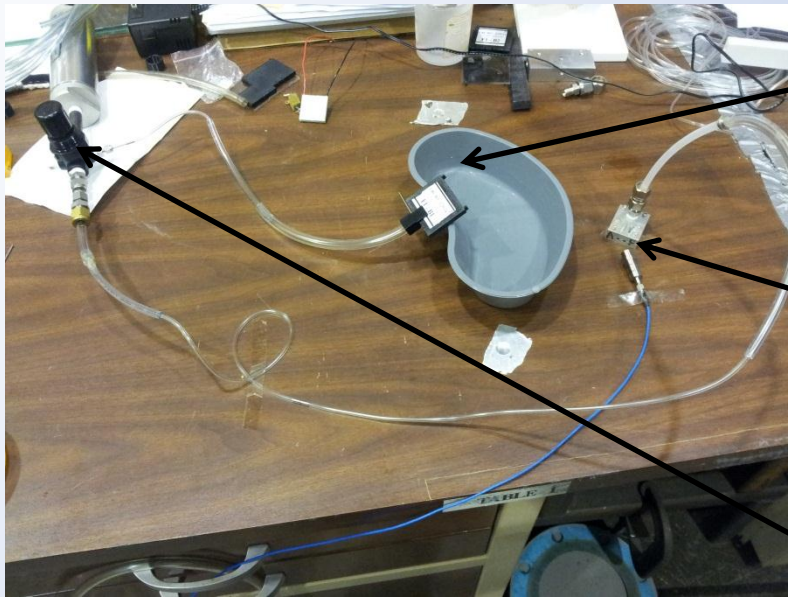


Without
Suction



ACFC Prototype Demo

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Fluidic Tests

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